BODY-WAVE MAGNITUDES AND LOCATIONS OF PRESUMED EXPLOSIONS AT THE CHINESE TEST SITE, 1967-1996

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ABSTRACT

For nearly 40 years the forensic seismology group at Blacknest have published estimates of the basic parameters of presumed explosions (epicentre, origin time, body-wave magnitude) determined using state-of-the-art methods from bulletin data (usually the International Seismological Centre (ISC) bulletin). These basic parameters are widely considered to be some of the most reliable estimates that are freely available. However, not all presumed explosions have been analysed.

Here, we estimate the epicentres and body-wave magnitudes of presumed underground explosions at the Chinese test site in Xinjiang Province using ISC bulletin data, supplemented by P-onset times measured from data recorded by the four UK-type seismometer arrays (EKA, GBA, WRA, YKA). The epicentres are estimated using Joint Epicentre Determination. The body-wave magnitudes are calculated using the Joint Maximum-Likelihood method. This work builds on an earlier report that reviewed epicentres and body-wave magnitudes for 17 presumed Chinese explosions fired between 1967 and 1989. A further 11 presumed explosions, dated from 1990 to 1996, are analysed to complete the set.

The estimates of the epicentres of the presumed explosions suggest that a number of different regions exist within the test site. The seismograms at each of the UK-type arrays for these presumed explosions appear to display common features which may relate to specific regions of the test site. Here, we attempt to distinguish the different areas of the test site using the P-wave characteristics observed at the 4 UK-type arrays.

Key Words

Location, body-wave magnitudes, Xinjiang Province, P-wave characteristics, UK-type seismometer arrays

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OBJECTIVE

The objective of this research is to provide reliable magnitude and location estimates for underground explosions at the Chinese test site. From the epicentre relocations we can assess how accurately epicentres can be located and demonstrate how well the onset times are read for explosions. We expect the seismograms from explosions to be simple but this study illustrates that they are often complex and highly variable, even for test areas within less than one hundred kilometres of each other. It is important to investigate this variability in order to use complexity as a discriminant.

RESEARCH ACCOMPLISHED

Introduction

Using P times and amplitude observations taken from the bulletins of the International Seismological Centre (ISC), Douglas et al (1993) obtain estimates of the body-wave magnitudes (m_b), epicentres and origin times of 17 Chinese explosions that took place between 1967 and 1989; 7 being fired in the atmosphere at the Lop Nor site, and 10 underground at the Singer site.

Since 1989 11 more presumed underground explosions have been reported from the Singer site in the ISC bulletins. Here we extend the work of Douglas et al (1993) and give estimates of magnitudes and locations for all 21 presumed underground tests (Table 1 lists these tests). In addition to the bulletin data taken from the ISC, some experiments are described on epicentre estimation using the P onset times read as part of this study from the recordings of the four UK-type arrays (EKA, GBA, WRA, and YKA). The purpose of the experiments is to see how well epicentres can be estimated using carefully read onset times from small numbers of stations, as compared to those using bulletin data from large numbers of stations. The distance, azimuth and back-azimuth of the arrays from the Singer site is given in Table 2.

The epicentres and origin times are re-calculated using joint epicentre determination (JED; Douglas 1967). Estimating epicentres and station terms simultaneously for groups of explosions gives better estimates of relative positions than is possible when each disturbance is considered individually. Given the true location of at least one explosion, the best estimates of absolute position can be found.

The magnitudes are estimated by the joint maximum-likelihood (JML) method of Lilwall (1986) and Lilwall and Neary (1985), which makes allowance for the detection thresholds of the recording stations. As magnitude decreases, then increasingly, below average amplitudes are not reported because they are below the detection threshold. As a result of this the mean magnitude estimated from the detecting stations is biased high. However, the maximum-likelihood magnitude m_b^{ML} should be unbiased.

Table 1 lists the 21 underground explosions for which times and amplitudes are published by the ISC and shows which of the explosions were recorded by the UK-type arrays. Douglas et al (1993) show that there are three separate test areas within the Singer site, here referred to as the Northern (N), Eastern (E) and South-Western (SW) areas. The area in which each explosion took place is given in Table 1 with the ISC m_b and m_b^{ML}.

Douglas et al (1993) suggest, from an analysis of the topography of the area, that the Northern and South-Western test areas are in mountainous regions, whereas the Eastern area is in a region of little relief. Matzko (1994) suggests that the explosions in the Eastern area were fired at the bottom of shafts. As the Northern and South-Western areas are in mountains, it may be that the explosions in these region were fired in tunnels driven into the hillsides (Douglas et al 1993)

Epicentre Relocations

Figure 1 shows the ISC epicentres for the 21 explosions and Figure 2 the JED results obtained using the ISC times. The JED estimates obtained using only the onsets read from the recordings at the UK-type arrays are also shown in Figure 2. Some recordings required an optimum frequency filter (Douglas 1997) to reduce low frequency noise and give a more reliable estimate of the onset time. The 4 May 1983 and 29 September 1988 explosions are not included in the analysis of the array data because

Explosion #	Date	YKA	EKA	WRA	GBA	ISC	m_b^{ML}	Test Area
1	690922	*	*	*	*	5.2	5.10	SW
2	751027	*	*	N	*	5.0	4.80	SW
3	761017	*	*	*	*	4.9	4.84	N
4	781014	*	*	-	*	4.9	4.54	E
5	830504	*	-	-	*	4.5	4.08	N
6	831006	*	*	N	*	5.5	5.45	E
7	841003	*	*	*	*	5.4	5.18	E
8	841219	*	N	*	*	4.7	4.38	N
9	870605	O	*	*	*	6.2	6.22	E
10	880929	*	-	*	-	4.6	4.34	N
11	900526	N	*	*	*	5.5	5.26	E
12	900816	*	*	*	*	6.2	6.13	E
13	920521	*	*	O	*	6.5	6.58	E
14	920925	*	*	*	*	5.0	4.58	N
15	931005	N	*	*	*	5.9	5.84	E
16	940610	*	*	*	*	5.8	5.71	E
17	941007	*	*	*	*	5.9	5.82	E
18	950515	*	*	*	*	6.0	6.05	E
19	950817	*	*	*	*	5.9	5.97	E
20	960608	*	*	*	*	5.7	5.72	E
21	960729	*	*	*	*	4.7	4.24	N

Table 1: Presumed underground explosions at the Singer Test Site. A '*' indicates which arrays recorded each explosion. '-' denotes that a phase was not detected for a particular explosion at that array, 'O' means that the station was overloaded for this explosion and 'N' denotes that there was no data available for this explosion. Also given are the bodywave magnitudes taken from the ISC bulletin and the maximum-likelihood magnitude m_b^{ML} estimated here.

GBA			
Test Area	Epicentral Distance(°)	Azimuth(°)	Back-Azimuth(°)
Northern	29.56	201.9	16.7
South Western	29.21	202.0	16.9
Eastern	29.53	202.7	17.3
EKA			
Test Area	Epicentral Distance(°)	Azimuth(°)	Back-Azimuth(°)
Northern	57.82	317.6	62.2
South Western	58.05	317.7	62.5
Eastern	58.11	317.7	62.1
YKA			
Test Area	Epicentral Distance(°)	Azimuth(°)	Back-Azimuth(°)
Northern	74.53	10.8	342.4
South Western	74.89	10.8	342.3
Eastern	74.62	11.0	342.0
WRA			
Test Area	Epicentral Distance(°)	Azimuth(°)	Back-Azimuth(°)
Northern	74.66	135.4	326.0
South Western	74.44	135.3	325.7
Eastern	74.36	135.7	326.1

Table 2: Epicentral distance, azimuth and back-azimuth to each of the UK-type arrays from each of the test areas. The angles are measured from the centre of the test areas, taken to be 41.55N 88.72E for the Eastern Test area, 41.70N 88.35E for the Northern test area and 41.34N 88.28E for the South Western test area.

there are not enough observations for a stable epicentre to be estimated. For all of the JED estimates the epicentres of the explosions of 6 October 1983 and 3 October 1984 were restrained to the locations published by Matzko (1994), on the assumption that these are the true locations. All JED depths were restrained to zero. Table 3 gives the location and origin time results of both the array and ISC JED runs.

The ISC epicentres (Figure 1) do not clearly separate into test areas within the Singer site whereas the JED results, both using ISC data and array data, (Figure 2) do show three distinct areas. Table 1 shows that most of the explosions have been at the Eastern test area and that these are usually larger in magnitude than those in the other two areas.

The results using the array observations (Figure 2) show that, even though the number of stations is small (four), the three test areas can be resolved when the onsets are reliably read. The variance of the array observations is over 50 times smaller than that of the ISC data which is highly significant (Table 4).

The hypothesis that all the epicentres at the Northern area had in effect a common epicentre was tested. It was found that the difference between the estimated epicentres and a common epicentre is significant at the 4.5% level. A similar test for the Eastern area shows that the hypothesis that the explosions have a common epicentre must be rejected (epicentre shifts are significant at less than the 0.005% level).

Magnitude Estimates

The m_b^{ML} estimates are derived from the amplitude and period observations given in the ISC bulletins, using the amplitude-distance curve of Lilwall (1987). The station thresholds used are the same as those used by Douglas (1993) - as a first pass, the thresholds for 1989 have been assumed to stay constant up to 1996. The estimates of m_b^{ML} must therefore be taken to be preliminary until the assumptions made about the thresholds for the period 1990-1996 have been checked.

The variation in signal characteristics with both m_b^{ML} and areas within the Singer site are now being investigated. Inspection of the recordings from the UK-type arrays shows that the P seismograms differ

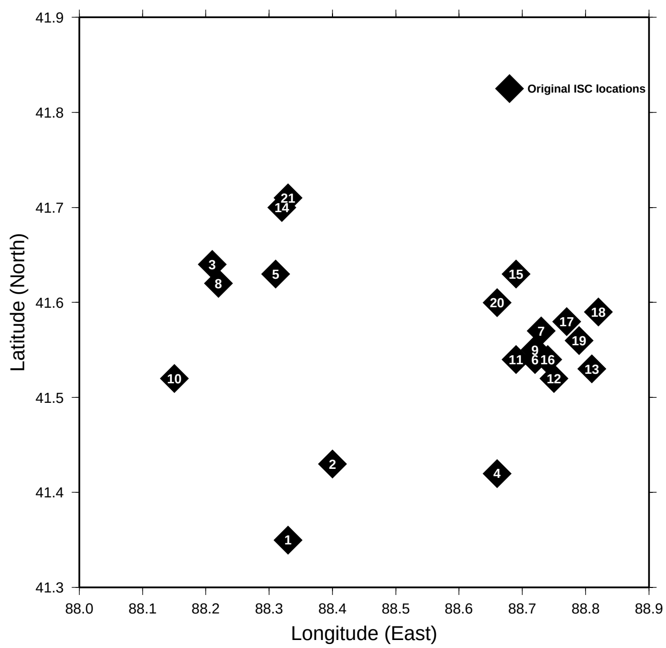

Figure 1: Original ISC coordinates for the underground tests at Singer. The numbers are the 'explosion #' given in Table 1.

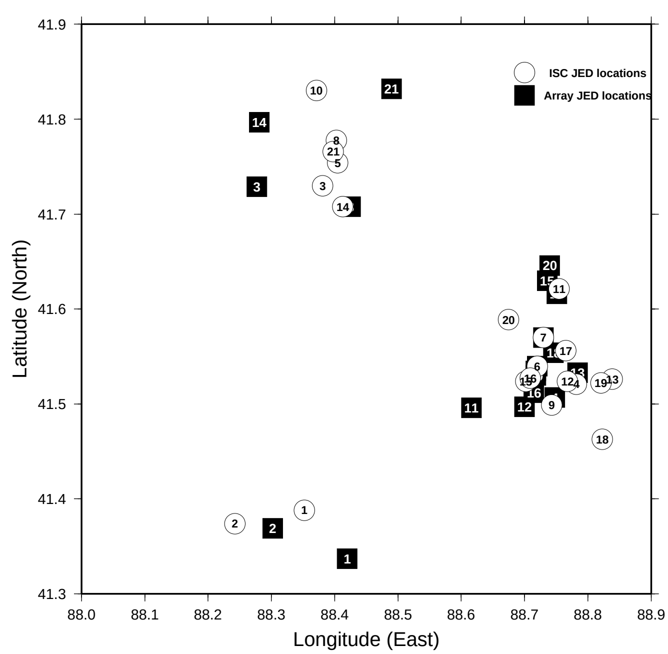

Figure 2: ISC JED relocations (circles) and the array JED relocations (squares). The numbers are the 'explosion #' given in Table 1.

Array JED results				
Explosion #	Date	Origin Time	Latitude	Longitude
1	690922	16:15:01.41±0.50	41.337N±8.5	88.420E±10.1
2	751027	0:59:59.94±0.57	41.369N±7.5	88.302E±13.9
3	761017	5:00:00.99±0.56	41.729N±7.5	88.277E±13.7
4	781014	0:59:59.69±0.57	41.507N±7.6	88.748E±13.8
6	831006	10:00:00.00±0.00	41.540N±0.0	88.720E±0.0
7	841003	6:00:00.00±0.00	41.570N±0.0	88.730E±0.0
8	841219	6:00:00.23±0.47	41.708N±8.3	88.425E±12.2
9	870605	5:00:00.37±0.40	41.535N±6.9	88.718E±9.3
11	900526	7:59:59.93±0.50	41.496N±8.5	88.616E±10.0
12	900816	4:59:59.79±0.40	41.497N±6.9	88.700E±9.3
13	920521	4:59:59.69±0.40	41.533N±6.9	88.784E±9.2
14	920925	8:00:01.04±0.39	41.797N±6.9	88.281E±9.3
15	931005	1:59:58.71±0.50	41.630N±8.5	88.736E±0.0
16	940610	6:26:00.15±0.40	41.512N±6.9	88.715E±9.3
17	941007	3:26:00.33±0.40	41.616N±6.9	88.751E±9.2
18	950515	4:06:00.17±0.40	41.554N±6.9	88.746E±9.3
19	950817	1:00:00.15±0.40	41.530N±6.9	88.718E±9.3
10	960608	2:56:00.34±0.40	41.646N±6.9	88.740E±9.2
21	960729	1:49:00.54±0.40	41.832N±6.9	88.490E±9.3

ISC JED results				
Explosion #	Date	Origin Time	Latitude	Longitude
1	690922	16:15:01.06±0.67	41.388N±2.2	88.352E±10.1
2	751027	1:00:00.60±1.20	41.374N±6.6	88.242E±18.9
3	761017	5:00:00.98±0.88	41.730N±3.3	88.381E±13.1
4	781014	0:59:59.83±0.86	41.521N±3.4	88.782E±12.6
5	830504	5:00:00.49±1.80	41.754N±1.4	88.405E±22.6
6	831006	10:00:00.00±0.00	41.540N±0.0	88.720E±0.0
7	841003	6:00:00.00±0.00	41.570N±0.0	88.730E±0.0
8	841219	6:00:00.63±0.71	41.778N±1.4	88.402E±8.4
9	870605	5:00:00.04±0.36	41.499N±7.6	88.743E±5.6
10	880929	7:00:00.50±0.90	41.830N±5.2	88.371E±9.2
11	900526	8:00:00.31±0.41	41.621N±8.4	88.755E±5.3
12	900816	4:59:59.67±0.34	41.524N±7.2	88.768E±4.8
13	920521	4:59:59.27±0.33	41.526N±7.3	88.839E±4.7
14	920925	8:00:00.40±0.47	41.708N±8.9	88.413E±6.3
15	931005	1:59:58.22±0.35	41.524N±7.8	88.702E±4.9
16	940610	6:26:00.22±0.36	41.527N±7.6	88.709E±4.9
17	941007	3:25:59.90±0.35	41.556N±7.4	88.765E±4.9
18	950515	4:05:59.36±0.35	41.463N±7.3	88.823E±5.0
19	950817	0:59:59.65±0.38	41.522N±7.6	88.821E±5.4
10	960608	2:55:59.92±0.38	41.589N±7.6	88.675E±5.4
21	960729	1:48:59.92±0.49	41.766N±8.9	88.398E±7.0

Table 3: JED results of location and origin time for both the array and ISC JED runs. The location confidence limits are given in kilometres.

JED run	No. of Explosions	Stan. Dev.	Variance	DoF	Restrained explosions
All Test areas					
ISC	28	2.0413	4.1670	5204	831006 and 841003
4 Arrays	23	0.2774	0.0770	13	831006 and 841003

Table 4: Results from the ISC and array JED runs using all underground explosions from the Singer test site.

for the three test areas. These differences are particularly clear on the GBA seismograms (Figure 3). The differences seem most likely to be due to lateral variations in structure near the test site but the details of this variation have still to be examined.

Other evidence of differences in near source effects of the three test areas is shown in such features as the period of the first P arrival. Figure 4 shows the period against m_b^{ML} for all GBA recordings. For the Northern area the period has a wide range even though the range of m_b^{ML} is small, whereas the periods for explosions at the Eastern area show the clear systematic increase with m_b^{ML} that might be expected as the corner frequency of the P pulse should decrease with yield and hence magnitude.

Figure 5 shows that there is a large discrepancy between the GBA station magnitudes and the station magnitudes at the other arrays, especially for the Eastern test area explosions. The rms values, however, show much better correlation (Figure 6), indicating that anomalous P-wave amplitudes can produce suspect station magnitude results, while rms values are more stable. The complexity of the GBA seismograms appears to be due to a reduction in the amplitude of the first arrival rather than an increase in the coda amplitude as seen in Figure 5 and Figure 6.

CONCLUSIONS AND RECOMMENDATIONS

The experiments using JED show that well-read onset times from four array stations are sufficient to resolve the distribution of epicentres into three separate test areas. It is to be hoped that the onset times measured at the IDC for explosions and published in the REBs can achieve similar accuracy.

To try and further improve the JED locations the array observations will be merged with those from the ISC and JED estimates will be obtained with the two sets of observations weighted appropriately. We also intend to analyse the REB onset times that are available for the four of the Singer tests to estimate the errors in the times. Further work is needed to investigate the anomalous P amplitudes at GBA and a large phase that is visible 20 seconds after the onset on the GBA recordings of the Eastern explosions only.

To improve the m_b^{ML} estimates, the maximum likelihood magnitudes will be recomputed, once the station threshold values have been determined for the time period from 1990-1996.

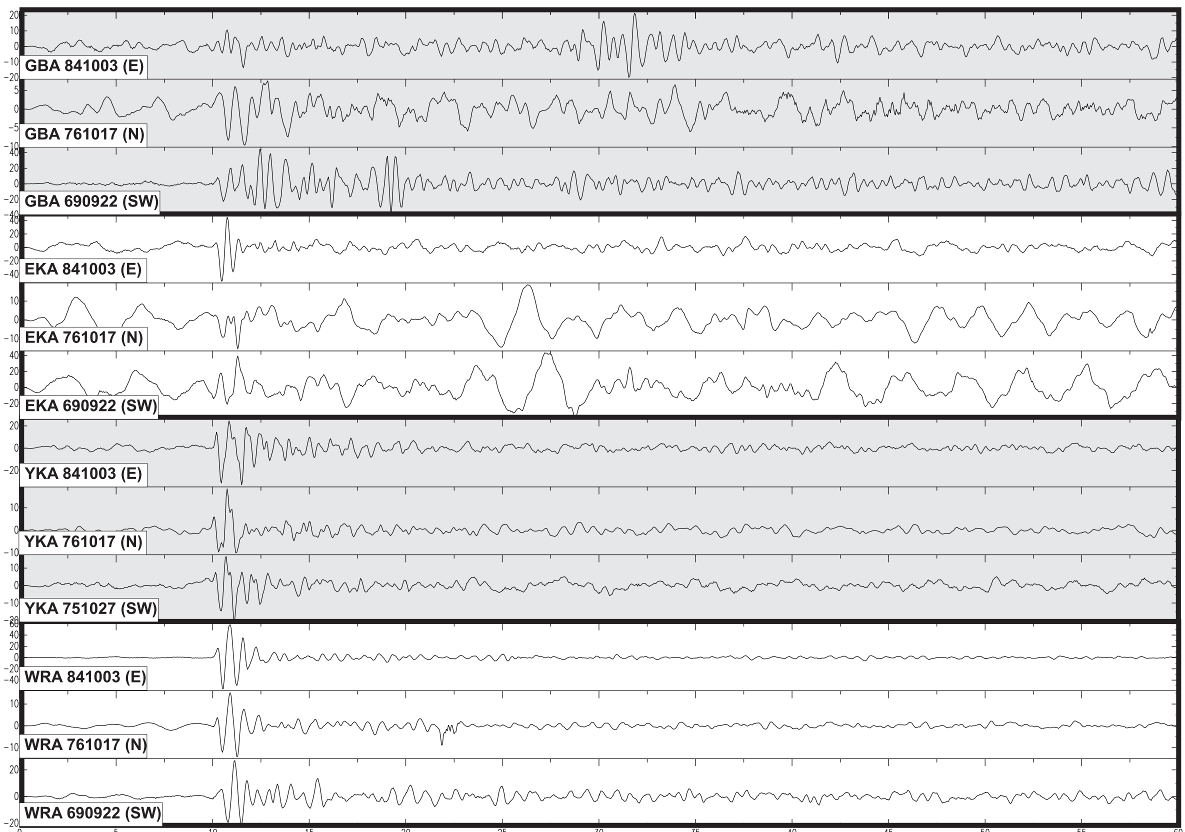

Figure 3: Unfiltered P beams from GBA, EKA, YKA and WRA for explosions of similar magnitude from the three test areas.

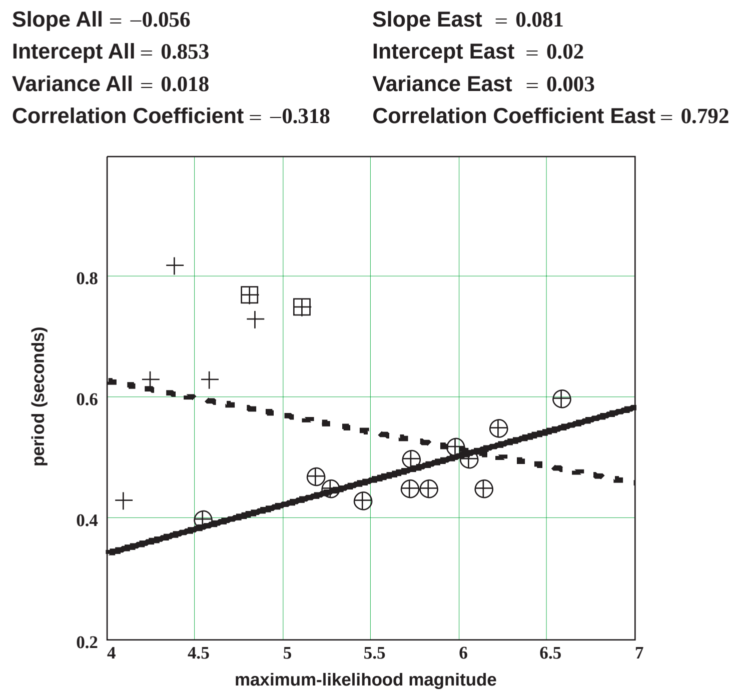

Figure 4: Period against m_b^{ML} for all explosions recorded at GBA. Two least squares lines are shown, the dashed line illustrates the estimate for all of the tests whereas the solid line is for the Eastern test area only.

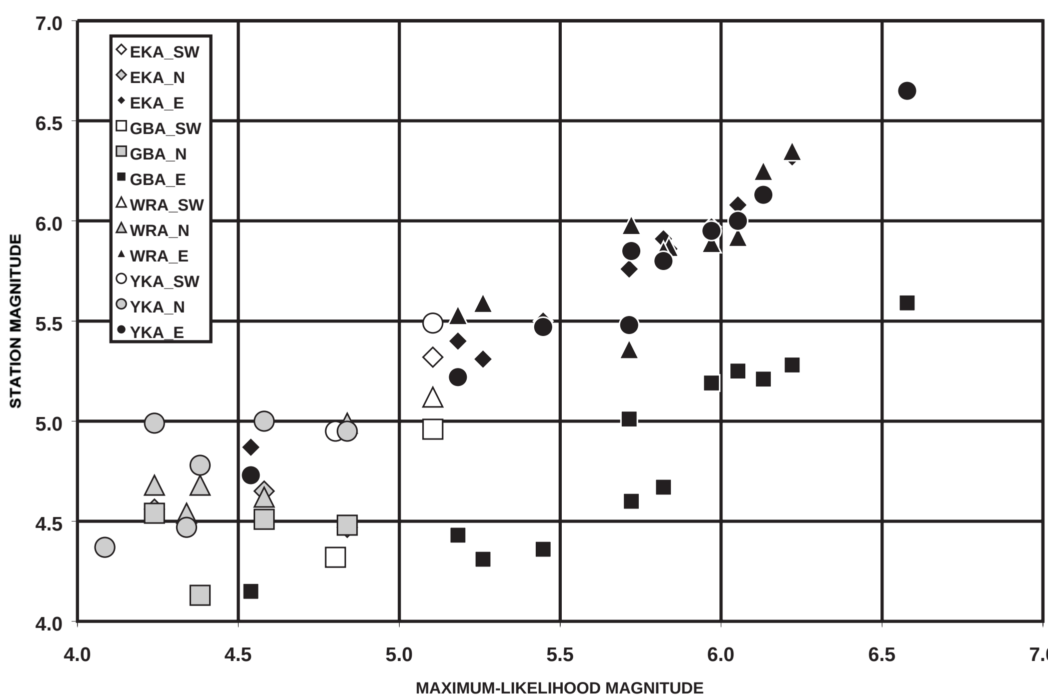

Figure 5: Station magnitude values for all arrays and all test areas. Note the anomalous GBA_E values.

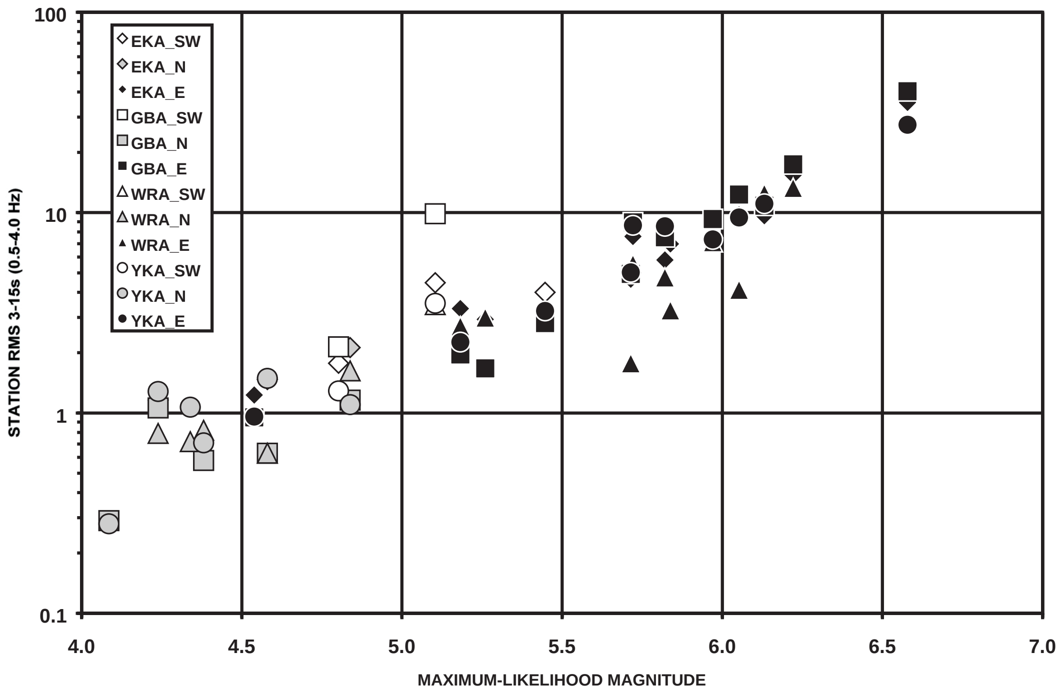

Figure 6: Station rms values for all arrays and all test areas for a time window from 3-15 seconds after the onset time. Note that all the arrays show similar values, even GBA_E.

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